Appendix D
Bulkheads

D-1. Sheetpiling

Sheetpiling, available in various materials including steel, aluminum, concrete, and timber, is used in bulkheads that may be either cantilevered or anchored. Detailed design procedures are available in EM 1110-2-2906 or in standard references such as United States Steel Corporation (1975). Cantilevered bulkheads derive their support solely from ground penetration; therefore, the effective embedment length must be sufficient to prevent overturning. Toe scour results in a loss of embedment length and could threaten the stability of such structures. Anchored bulkheads gain additional support from anchors embedded on the landward side or from structural piles placed at a batter on the seaward side. Connections between the anchors and the bulkhead should be suitably corrosion protected. Horizontal wales, located within the top one third of the bulkhead height, distribute the lateral loads on the structure to the anchors.

D-2. Steel Sheetpiling

a. General. Steel sheetpiling is the most widely used bulkhead material. It can be driven into hard, dense soils and even soft rock. The interlocking feature of the sheet-pile sections provides a relatively sand- or soil-tight fit that generally precludes the need for filters. This close fit may also be essentially water-tight, so regularly spaced weep holes are recommended. These and lifting holes in the piling should be backed with a proper filter to preclude loss of backfill material.

b. Prototype installations (Figures D-1 and D-2). Prototype performance is well documented and known through the experience gained at hundreds of sites throughout the United States.

D-3. Timber Sheetpiling

a. General. Well-designed and well-built timber structures have long been recognized as viable and economical for marine use. At marine locations, only treated timber with corrosion-resistant or protected metals for hardware and fasteners should be used. Wrought iron anchor rods with turnbuckles and bolts have good durability, as do galvanized fasteners. Washers should be placed under bolt heads and nuts to ensure even bearing, but the number of these should be minimized to reduce the exposed length of bolt shanks. Bolt holes should be no larger than required to provide a tight fit through the timbers. Joints between the timber sheeting should be minimized, and the use of a filter is recommended as an added precaution.

b. Prototype installations. Timber sheet-pile bulkheads have been installed at numerous locations throughout the United States. Their performance is well known and documented. A typical installation is shown in Figure D-3 and details of the construction are in Figure D-4.

D-4. Aluminum Sheetpiling

a. General. Aluminum sheetpiling has been sold since 1969 and has been used successfully in many applications since then. Advantages of aluminum are light weight (2 to 4 lb/ft^2), installation ease, good strength-to-weight ratios, and excellent corrosion resistance. The main disadvantage of aluminum compared to steel is that it cannot be driven through logs, rocks, or other hard obstructions. Special design and construction suggestions are available from suppliers (Ravens Metal Products 1981; Kaiser Aluminum and Chemical Sales 1979).

b. Corrosion characteristics. Aluminum has excellent corrosion resistance in a wide range of water and soil conditions because of the tough oxide film that forms its surface. Although aluminum is an active metal in the galvanic series, this film affords excellent protection except in several special cases. The first of these is the alloy composition of the aluminum itself. Alloys containing copper or silicon alone are susceptible to corrosion and should not be used. Second, differing mechanical or thermal treatment across the surface of the metal can set up electrical potential differences that could lead to corrosion. Therefore, welding should be done with care; and lifting holes, if needed, should be drilled rather than burned. Third, the oxide film is generally stable in the pH range of 4.5 to 8.5, but the nature of the dissolved compounds causing the pH reading is crucial. For instance, acidic waters containing chlorides are more corrosive to aluminum than those containing sulfates. Fourth, galvanic corrosion with dissimilar metals can be troublesome, particularly when contact is made with copper or carbon steel. Finally, certain soils tend to be corrosive to aluminum, particularly nondraining clay-organic mucks. As a general rule, contact with clay soils should be minimized unless special corrosion treatment measures are instituted. Where questions exist, expert advice should be sought from CERL.

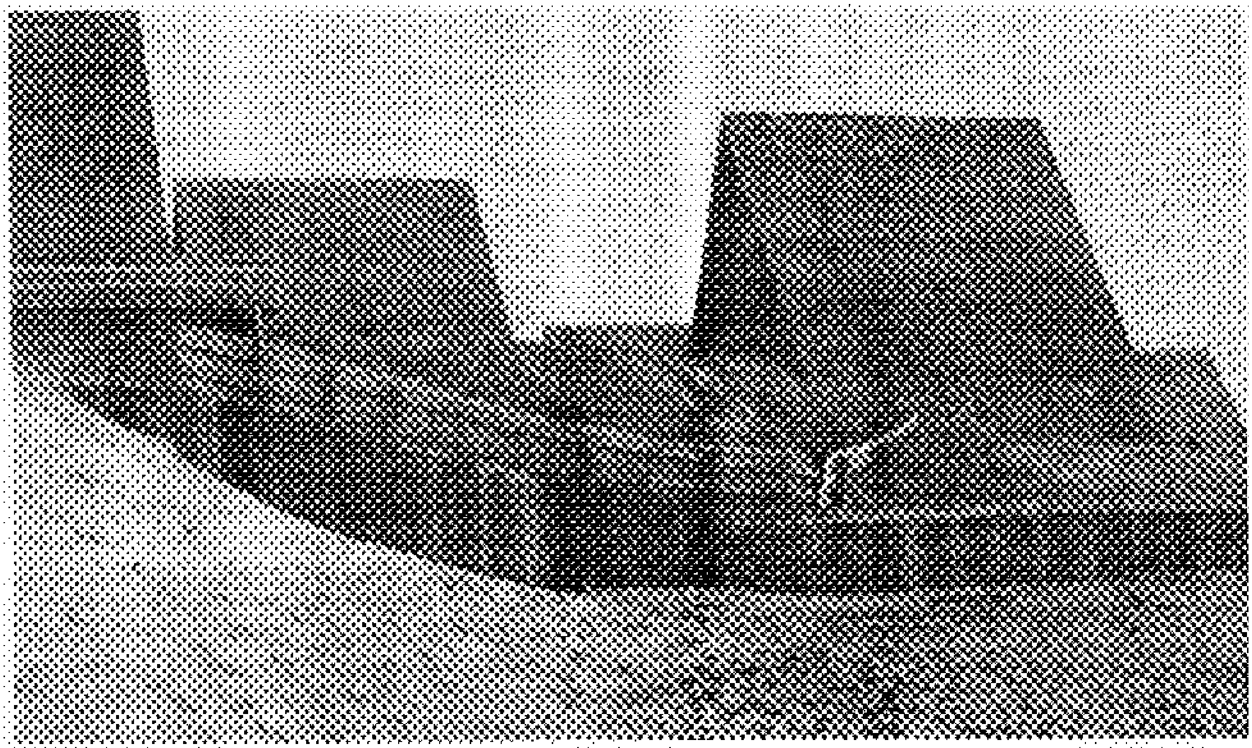

Figure D-1. Sheet-pile bulkhead, Lincoln Township, MI

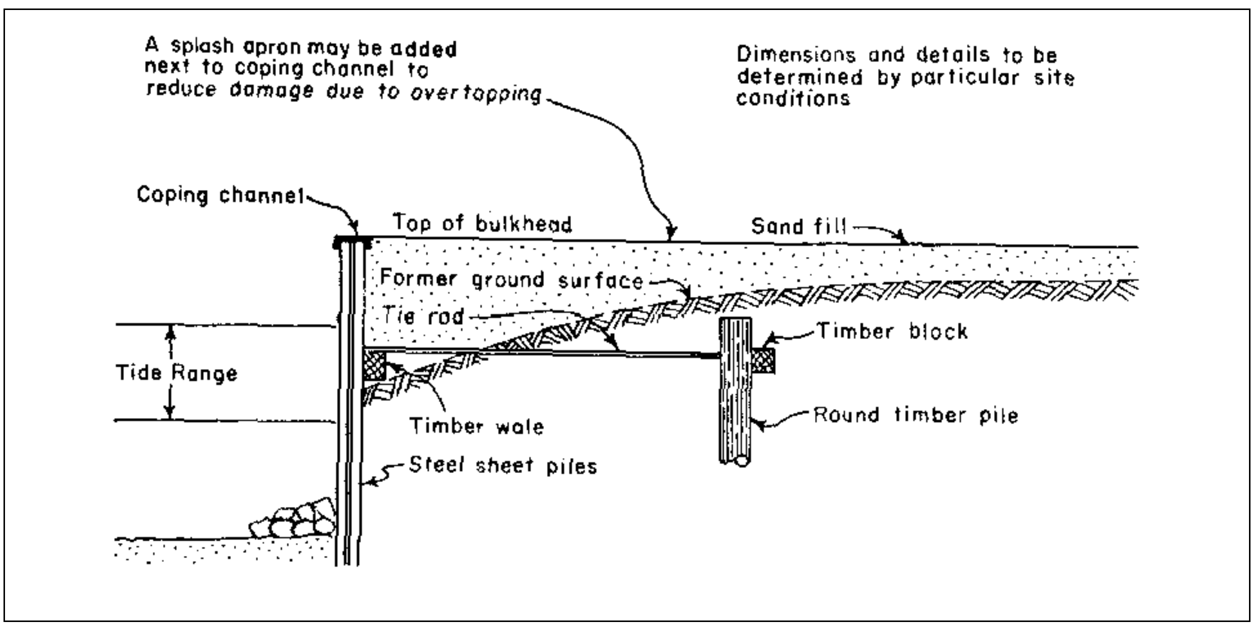

Figure D-2. Steel sheet-pile bulkhead cross section

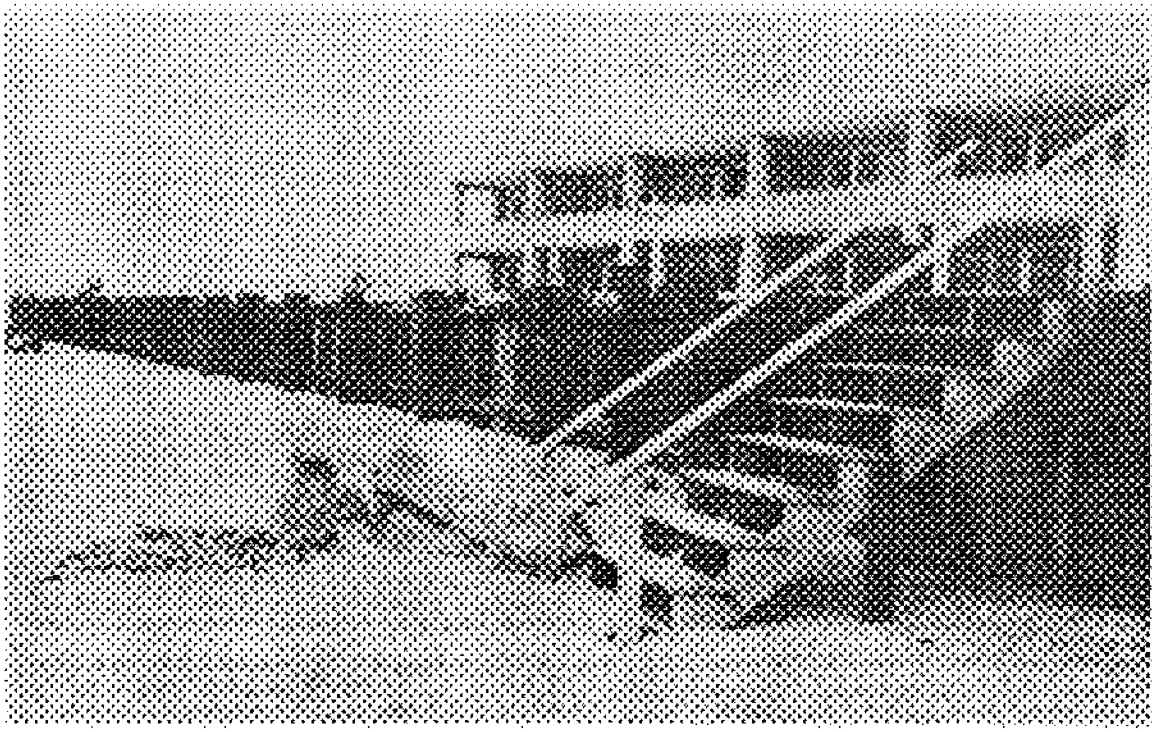

Figure D-3. Timber sheet-pile bulkhead, possibly at Fort Story, VA

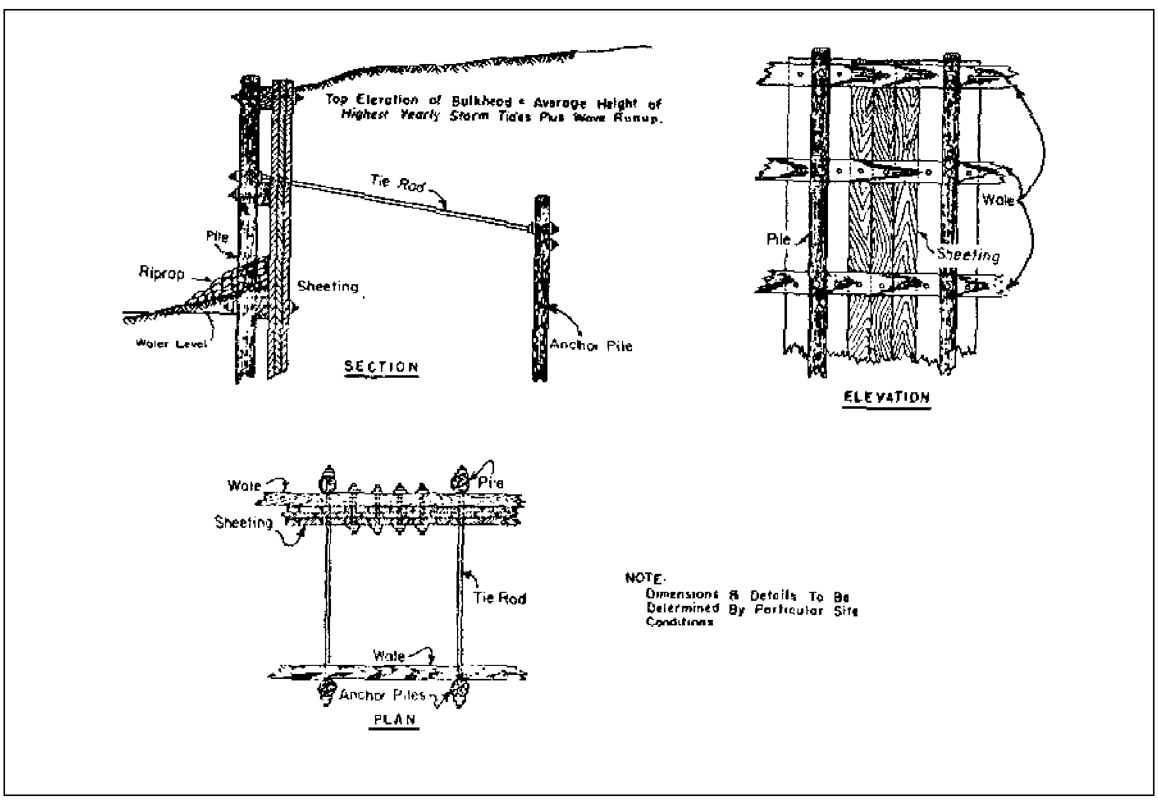

Figure D-4. Construction details of timber sheet-pile bulkhead *c. Prototype installations (Figure D-5).* Aluminum sheetpiling has been installed at numerous locations around the country, including Bowens Inn, Calvert County, MD; Ocean Pines, Ocean City, MD; Hilton Head Island, SC; and West Bay, Galveston Island, TX. Specific performance data on these installations are unavailable.

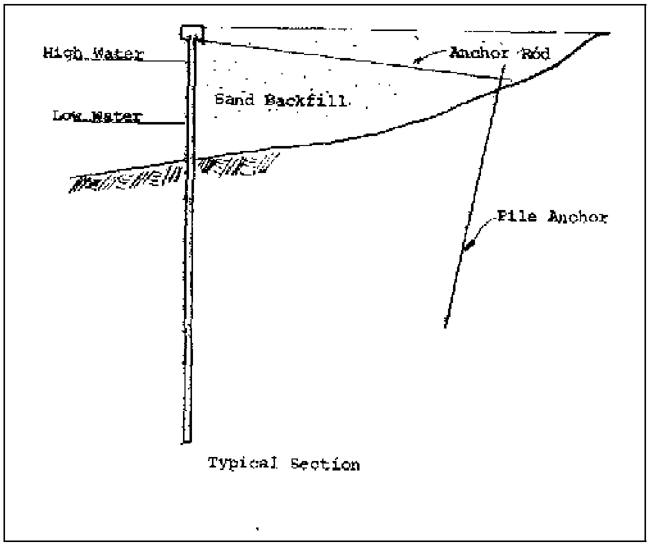

Figure D-5. Aluminum sheet-pile bulkhead cross section

D-5. Concrete Sheetpiling

a. General. Prestressed concrete sheetpiling has been used throughout the United States. It is particularly advantageous where abrasion, corrosion, or marine-borer activity limits the use of other types of sheetpiling. While concrete sheetpiling is not generally available from most suppliers, it can be cast at the jobsite for large projects. Typical sections have a tongue-and-groove shape with thicknesses of 12 in. and widths of 3 ft. The actual dimensions for a given project will be a function of design loads.

b. Prototype installations. Figure D-6 shows a concrete sheet-pile bulkhead that was constructed at Folly Beach, SC. The design cross section is probably very similar to that shown in Figure D-1, with the exception that concrete was used. No specific design details were available for this structure.

D-6. Cellular Steel Sheetpiling

a. General. Cellular steel sheetpiling can be used in areas where adequate pile penetration cannot be obtained.

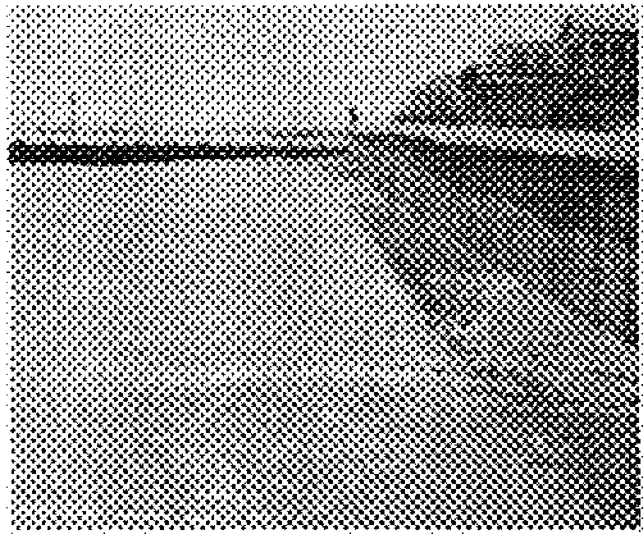

Figure D-6. Concrete sheet-pile bulkhead, Folly Beach, SC

A typical wall consists of cells, each constructed with semicircular walls connected by cross diaphragms. Each cell is then filled with sand, gravel, stone, or other material to provide structural stability. Unlike other sheet-pile structures, this is a gravity device that resists sliding by bottom friction and overturning by the moment supplied by its weight. Toe protection is crucial to prevent loss of fill through the bottom of the cell, and a concrete cap is necessary in most cases to protect against loss of fill due to overtopping waves. This is a higher cost and more massive equivalent of the used concrete pipe bulkhead described in paragraph D-17.

b. Prototype installation (Figure D-7). This type of construction has been used on the Great Lakes, primarily for groins. No specific bulkhead installations are known for which background information is available. A possible plan and cross section are shown in Figure D-7.

D-7. Post-Supported Bulkheads

Post-supported bulkheads consist of regularly spaced piles or posts with an attached facing material that retains the backfill. The posts, support components of the bulkhead, resist the earth and wave pressures that are generally distributed to them by the facing material. This type of bulkhead, like sheetpiling, can be either cantilevered or anchored.

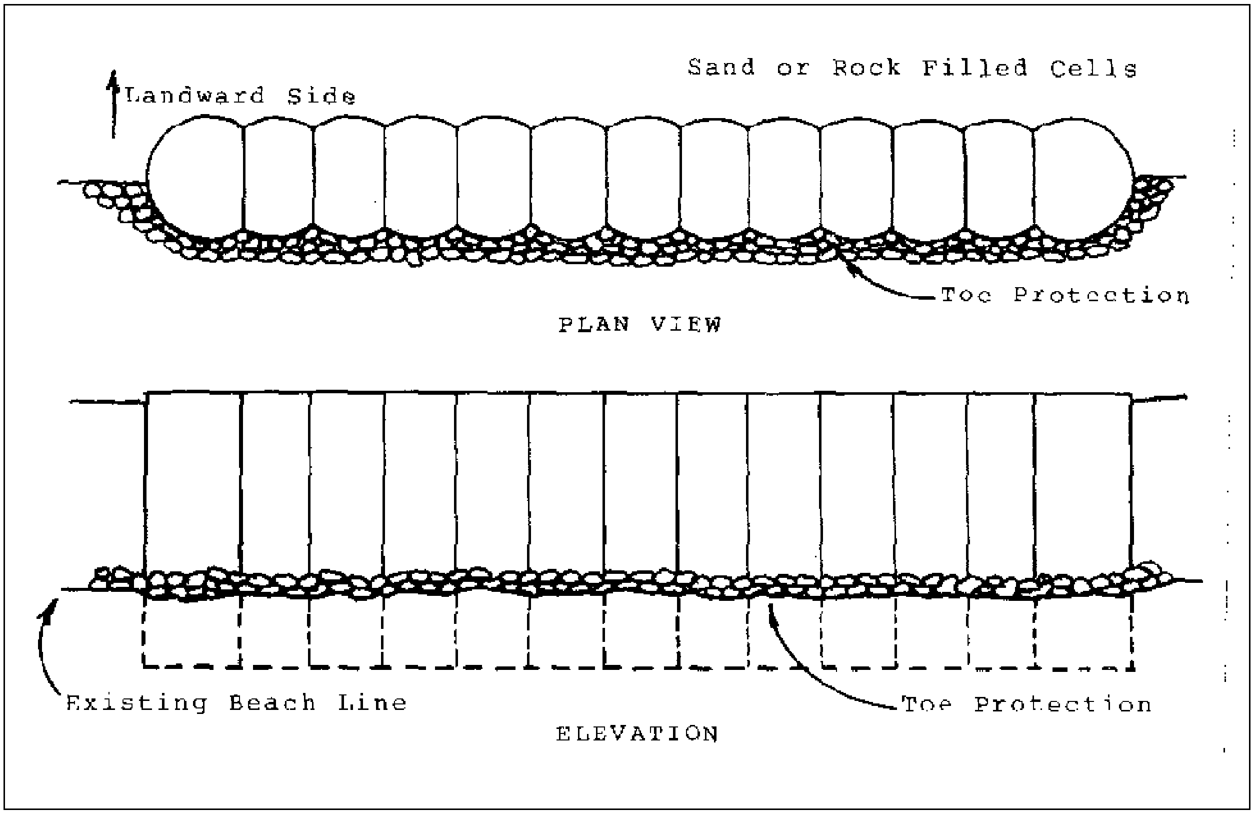

Figure D-7. Cellular steel sheet-pile bulkhead plan and cross section

D-8. Concrete Slabs and King-Piles

a. General. Conceptually, the system utilizes vertical concrete kingpiles that are H-shaped in section. Tongue-and-groove precast slabs are placed between the flanges of the king-piles to form a heavy, continuous retaining structure.

b. Prototype installation. This type of structure was built in 1953 at Virginia Beach, VA, and is shown in Figures D-8 and D-9. Features include a cast-in-place concrete cap, or headwall, which is used to support the seaward edge of a concrete walkway as shown in Figure D-9. Regularly spaced weep-holes are provided for hydrostatic pressure relief, and stairs, placed at intervals, provide access to the beach. The seaward toe of the stairs is pile supported, and the upper end is keyed into the concrete headwall.

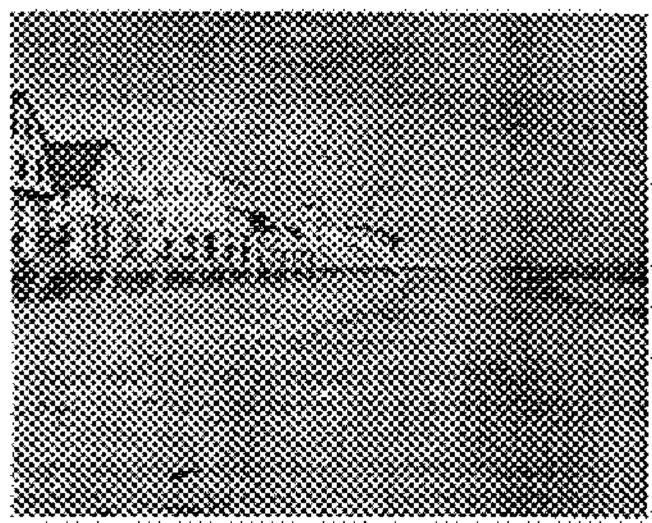

Figure D-8. Concrete slab and king-pile bulkhead

D-9. Railroad Ties and Steel H-Piles

a. General. Although utilizing different construction materials, this system is almost identical in concept to the previous one. The railroad ties, however, require a cap to retain them in place due to their natural buoyancy.

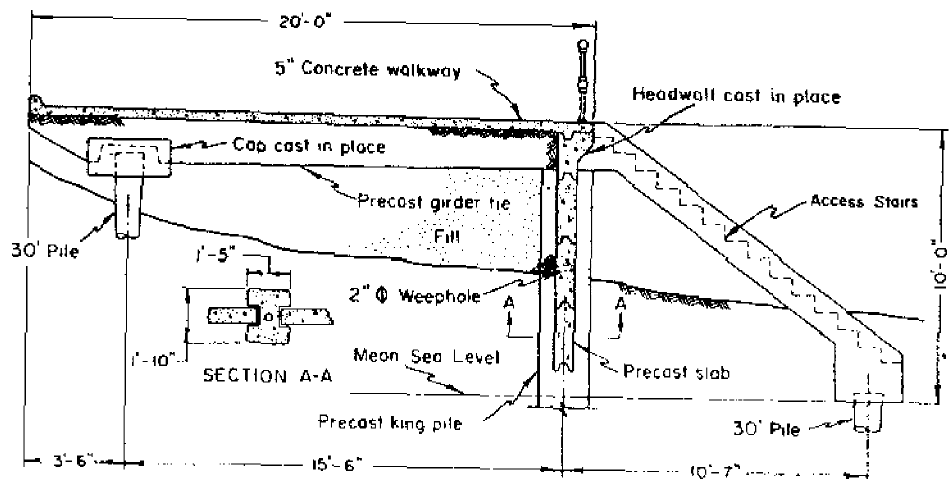

Figure D-9. Concrete slab and king-pile bulkhead cross section

b. Prototype installation (Figures D-10 and D-11). A bulkhead using this system was built at Port Wing, WI, in November 1978 (final report on the Shoreline Erosion Control Demonstration Program). The H-piles were set about 12 ft into the sandstone bedrock on 8-ft centers in holes drilled by a truck-mounted auger. After the piles were grouted in place, the railroad ties were placed between the flanges, and a steel channel was welded to the top. Rock toe protection was provided, and a non-woven filter cloth and granular backfill were used behind the wall. The structure subsequently weathered several severe storms with little or no structural damage.

D-10. Treated Timber

a. General. Horizontal, pressure-treated planks can be spiked to the landward side of the posts that are anchored to deadmen or piles in the backfill. The planks must be backed by filter cloth or graded stone to prevent soil losses through the cracks. Riprap toe protection should be provided.

b. Prototype installation (Figures D-12 and D-13). Devices of this kind are fairly common where timber is economical (final report on the Shoreline Erosion Control Demonstration Program). An excellent prototype example is a structure that was built at Oak Harbor, WA, in June 1978. Constructed at the base of a 30-ft-high bluff, it utilized treated 8-in.-square posts on 4-ft centers to which 3- by 12-in. planks were spiked. Anchors were connected to each post, the landward face was covered with a non-woven filter cloth, and rock toe protection was placed in front of the wall. The structure has withstood several storms with some damages due to loss of backfill through discontinuities in the filter cloth. Repairs of these faults improved subsequent performance and limited later damages.

D-11. Untreated Logs

a. General. Similar to the previous system, this method employs untreated logs as the basic construction material in lieu of treated timbers.

b. Prototype installation (Figures D-14 and D-15). A typical prototype structure was built at Oak Harbor, WA, in June 1978 (final report on Shoreline Erosion Control Demonstration Program). It consisted of large log posts spaced on 4-ft centers to which horizontal logs were spiked. These were backed by a gravel filter and granular backfill that provided the basic support to the structure under wave conditions. A February 1979 storm later washed out the gravel filter and backfill. Deprived of support from behind, the structure was essentially destroyed as the horizontal logs were displaced. A strong filter cloth capable of bridging the gaps between the logs may have yielded adequate performance and prevented failure by retaining the backfill.

D-12. Hogwire Fencing and Sandbags

a. General. Hogwire fencing attached to posts can be used to support sandbags stacked on the landward side

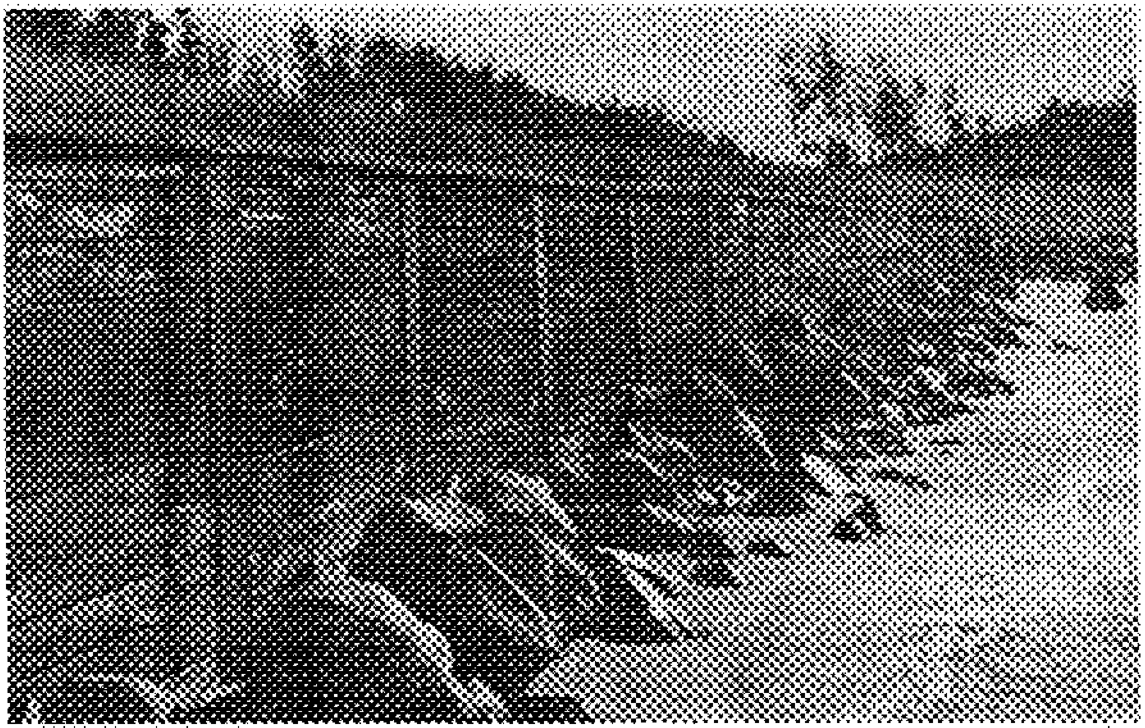

Figure D-10. Railroad ties and steel H-pile bulkhead, Port Wing, WI

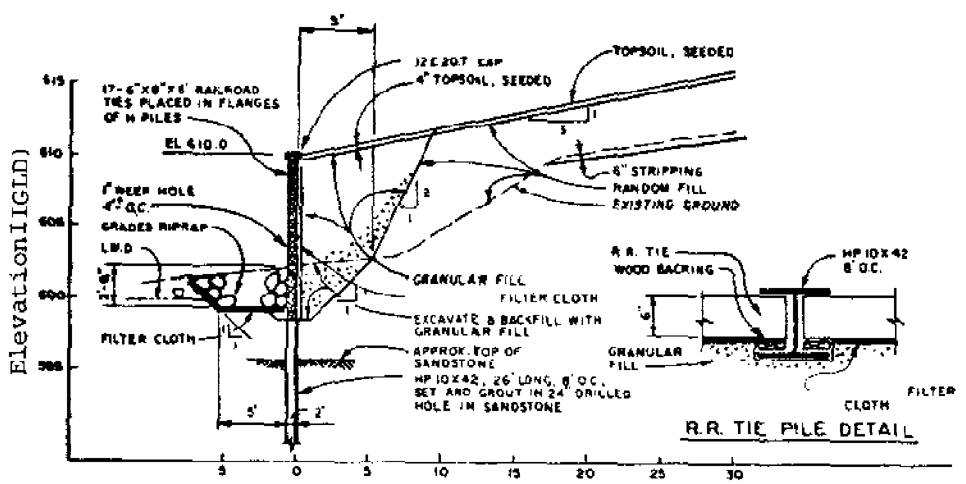

Figure D-11. Railroad ties and steel H-pile bulkhead cross section

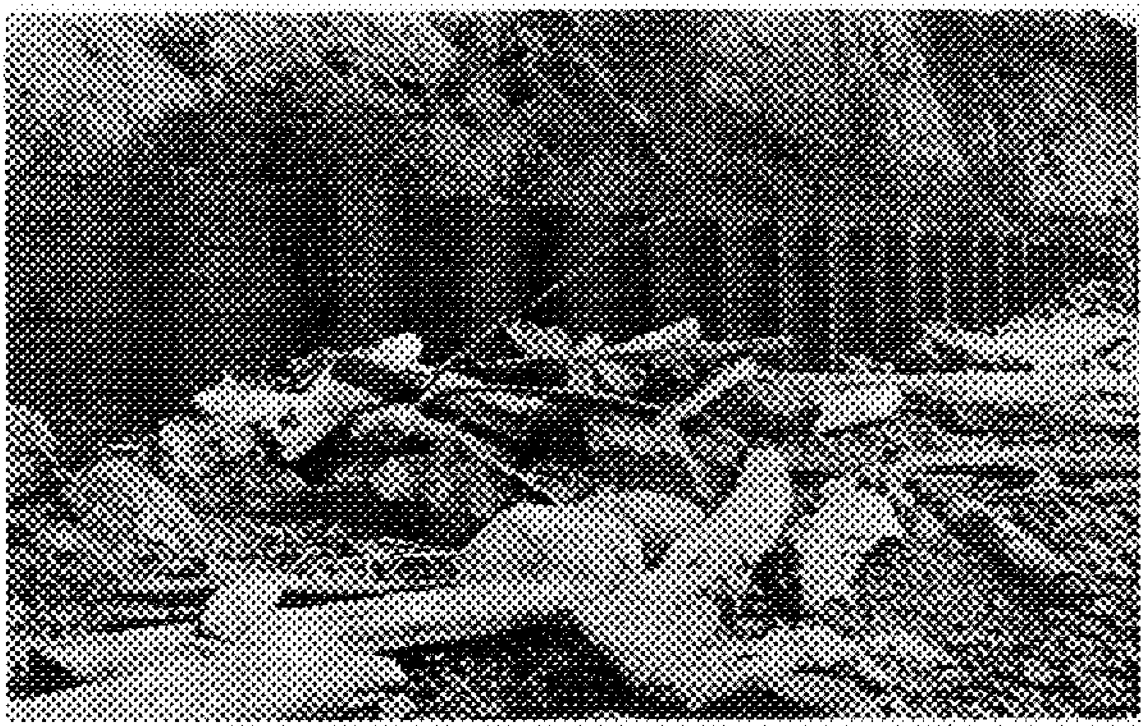

Figure D-12. Treated timber bulkhead, Oak Harbor, WA

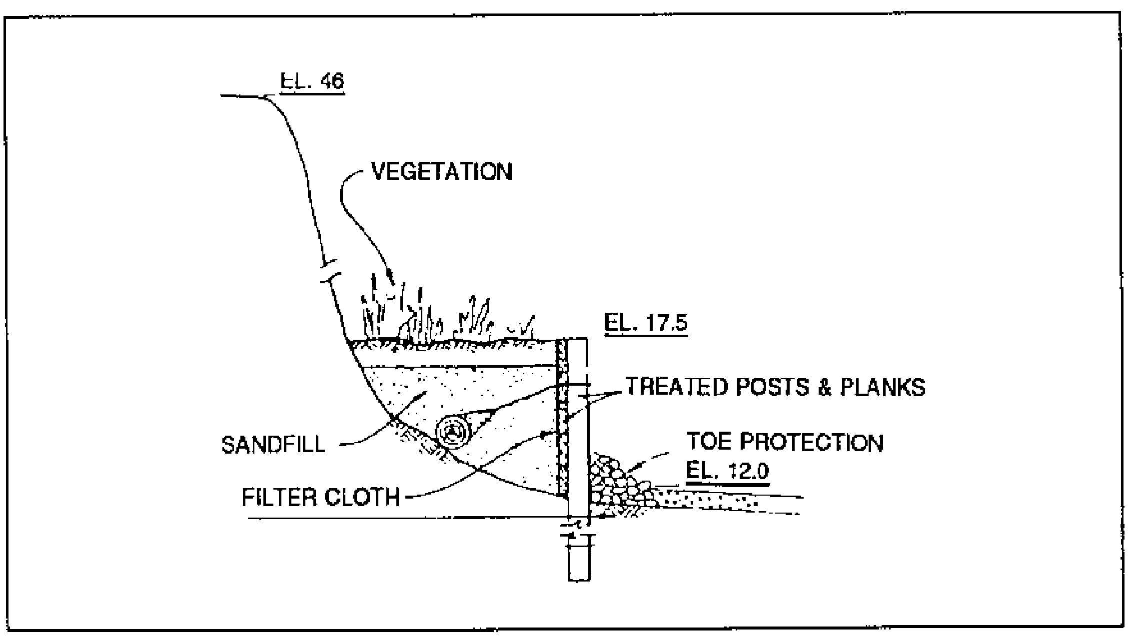

Figure D-13. Treated timber bulkhead cross section

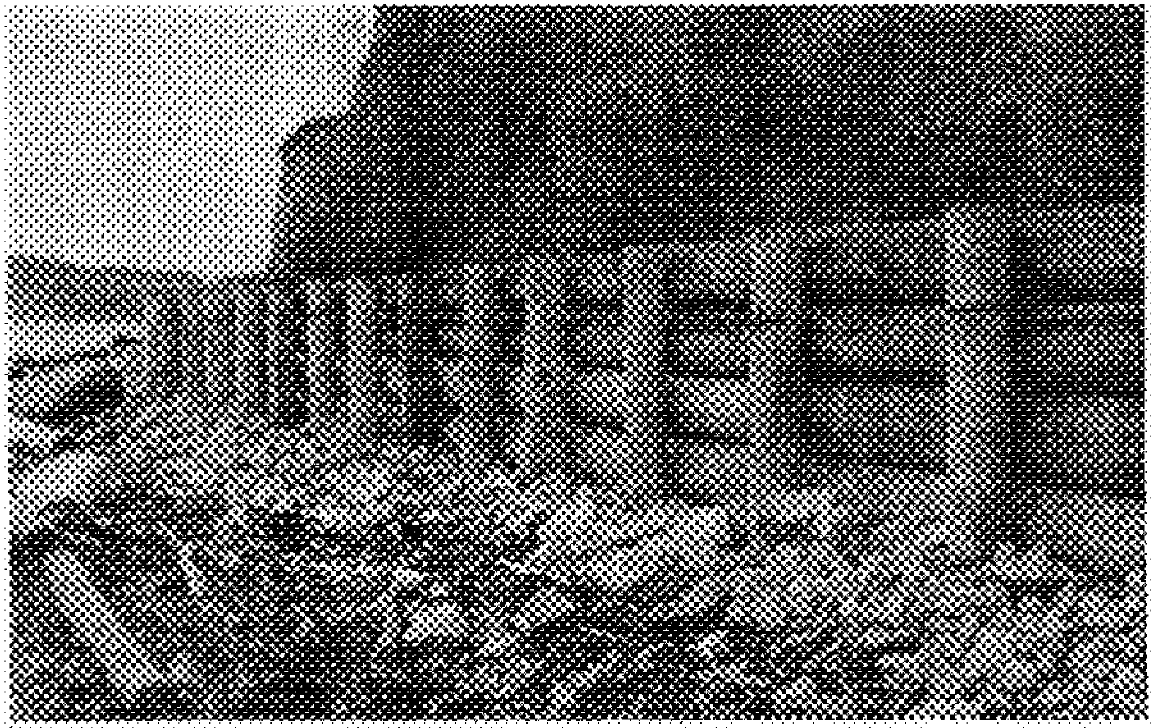

Figure D-14. Untreated log bulkhead, Oak Harbor, WA

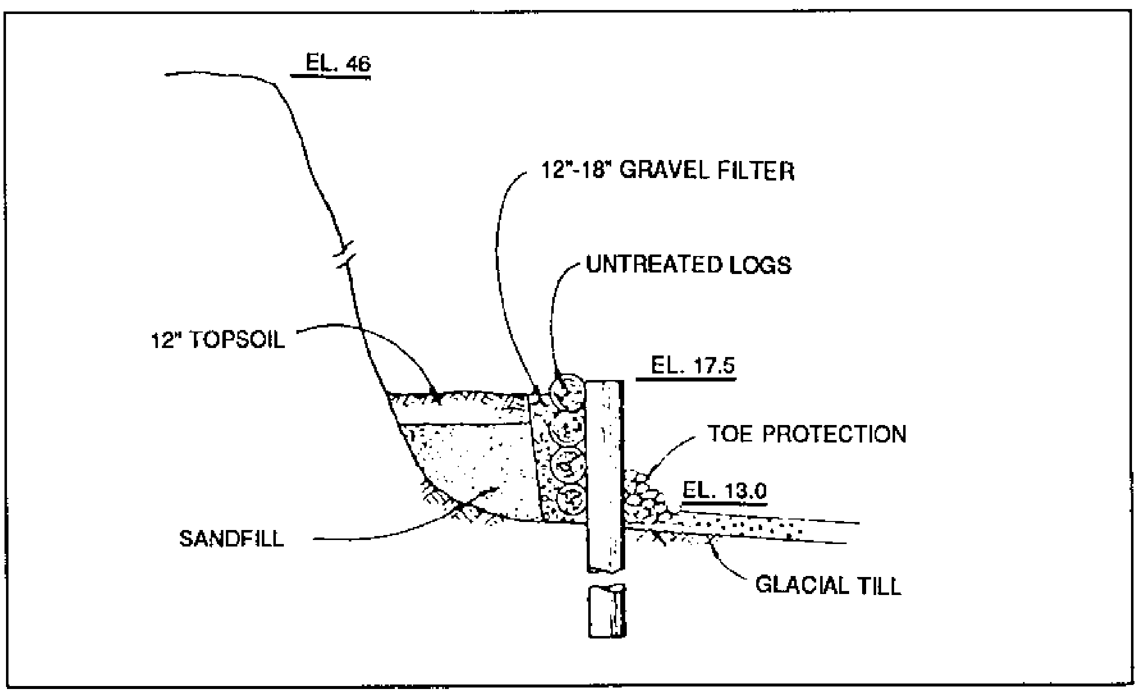

Figure D-15. Untreated log bulkhead cross section of the fence to form a relatively inexpensive structure. The sandbags are vulnerable to tearing, however, if they are undercut by toe scour and slide against the hogwire fencing. Best performance is achievable using PVC-coated, small mesh wire to minimize corrosion and damage to the bags. Tearing of the exposed front row of bags can be minimized by filling them with a sand-cement mixture. This allows the use of burlap bags in place of more expensive synthetic fabric bags that must be stabilized against ultraviolet light. Finally, the bags and fencing should be placed in a trench excavated to the anticipated scour depth to minimize shifting and damage to the bags.

b. Prototype installation (Figures D-16 and D-17). A 200-ft section of fence and bag bulkhead was used to protect a low bluff at Basin Bayou State Recreation Area, FL (final report on Shoreline Erosion Control Demonstration Program). Constructed in early December 1978, it consisted of timber posts at 5-ft centers with 36-in. hogwire fencing stretched between. The basic sections were constructed--one two bags wide and the other three bags wide. One half of each of these sections was constructed using acrylic bags and the other half using polypropylene bags. The structure failed after a short period of time when the polypropylene bags, which were not stabilized against ultraviolet light, disintegrated rapidly. The acrylic bags did not disintegrate, but they were not sufficiently entrenched and so were displaced and torn as toe scour proceeded. Adherence to the guidelines specified above would probably yield more acceptable results for short-to-medium-term performance.

D-13. Used Rubber Tires and Timber Posts

a. General. Closely spaced vertical posts can be strung with used rubber tires to form an inexpensive bulkhead. Tires are advantageous because they are tough and durable and are available free in most areas. The large gaps between the adjoining tires create a problem in providing an adequate filtering system.

b. Prototype installation (Figures D-18 and D-19). Used tire bulkheads have been constructed at many locations around the country (final report on Shoreline Erosion Control Demonstration Program). A good example is one that was built at Oak Harbor, WA, in the summer of 1978. Placed at the toe of a high bluff, it consisted of two rows of staggered posts with tires placed over them to form a structure approximately 4.5 ft high. The tires

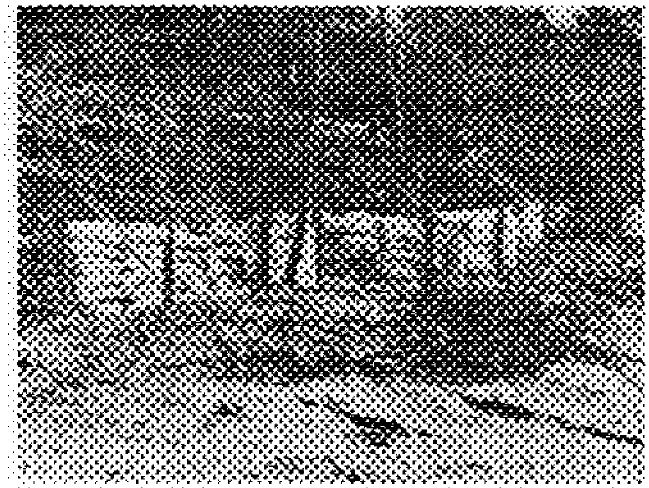

Figure D-16. Hogwire fence and sandbag bulkhead Basin Bayou Recreation Area, FL

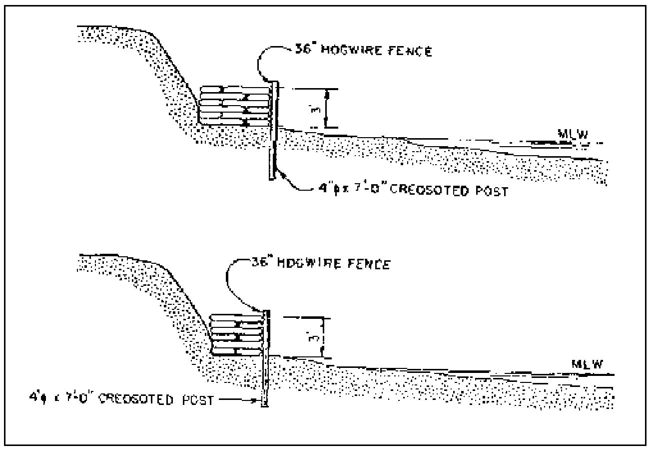

Figure D-17. Hogwire fence and sandbag bulkhead cross section

were filled with gravel as they were placed, and wire rope was used to fasten the posts to deadman anchors. Half of the structure had no filter, and the other half had equal segments of gravel and filter cloth protection. Storms that occurred after installation removed the backfill behind the unfiltered portion of the structure. The bulkhead experienced no structural damages, however, and the continued sloughing of the bluff eventually deposited enough material behind the bulkhead to allow natural sorting processes to form an effective filter cake. The filter-protected portions performed well throughout. Despite the ultimately successful performance of the unfiltered portion, a

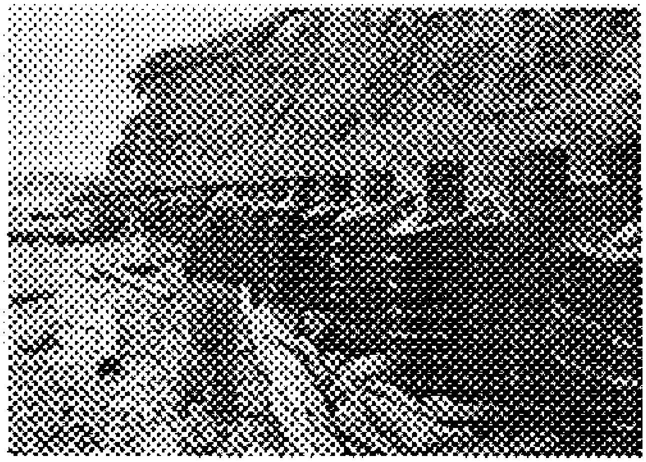

Figure D-18. Used rubber tire and timber post bulkhead, Oak Harbor, WA

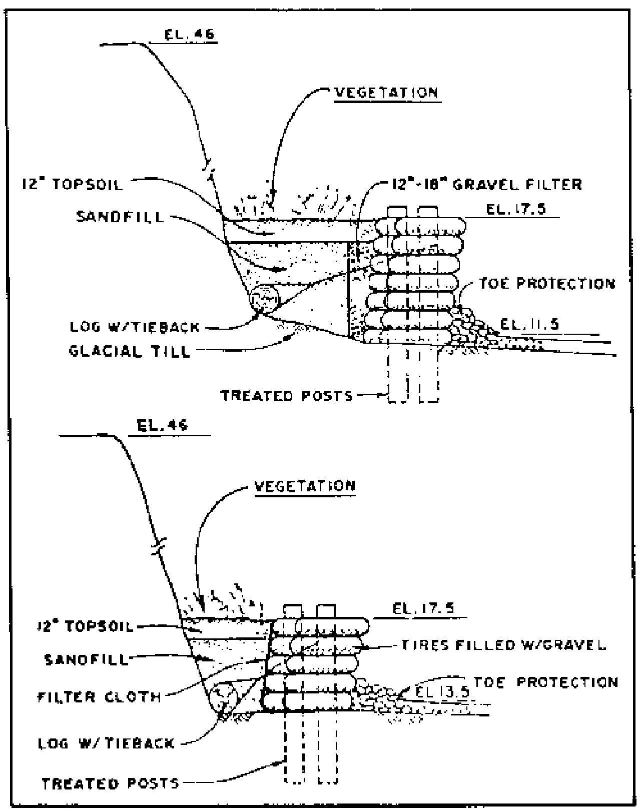

Figure D-19. Used rubber tire and timber post bulkhead cross section

structure such as this should always be constructed with a filter unless a large supply of well-graded backfill is available for a filter to form by sorting processes.

D-14. Miscellaneous

The following are basically gravity structures that depend on weight and sliding friction to retain the fill. They are generally easier to construct than post-supported bulkheads, yet they offer less stability in some cases because they do not penetrate subsurface failure surfaces that may be critical in some bluff situations.

D-15. Timber Cribbing

a. General. Timber crib bulkheads are constructed of heavy-duty timbers (6- by 6-in. minimum) that are stacked in alternating layers to form an open weave, box-like structure. This box is then filled with stone (at least 50 lb) to form a massive wave-resistant structure. Threaded rods with washers and nuts can be used at each corner to fasten the structure together. Adherence to filtering provisions and toe protection requirements is essential. If the gaps between the timbers are too large to retain the available stone, notching the ends will decrease the spacing between members.

b. Prototype installation (Figure D-20). Structures of this kind are located throughout the United States, particularly on the Great Lakes. In marine applications, care should be taken to use properly treated timber to resist marine borer activity.

D-16. Stacked Rubber Tires

a. General. Tires have often been tried for shore-protection devices because of their ready availability at most locations. These can be stacked in some pyramid fashion to form a bulkhead. Success depends in large measure on the strength of the interconnections between the tires, a common failure point for this kind of structure. While availability of tires is a strong temptation to use them for shore protection, they are extremely rugged and cannot be fastened securely together except by considerable effort and expense. In most cases, failures result from inadequate connections.

b. Prototype installations (Figures D-21 and D-22). A stacked tire bulkhead was constructed at Port Wing, WI, in July 1979 (final report on Shoreline Erosion Control Demonstration Program). The tires were placed flat, as shown, with the holes in successive layers of tires being staggered. A row of anchors on 10-ft centers was installed near the toe, middle, and top of the structure. The anchors were 0.75-in. galvanized rods with 4-in.

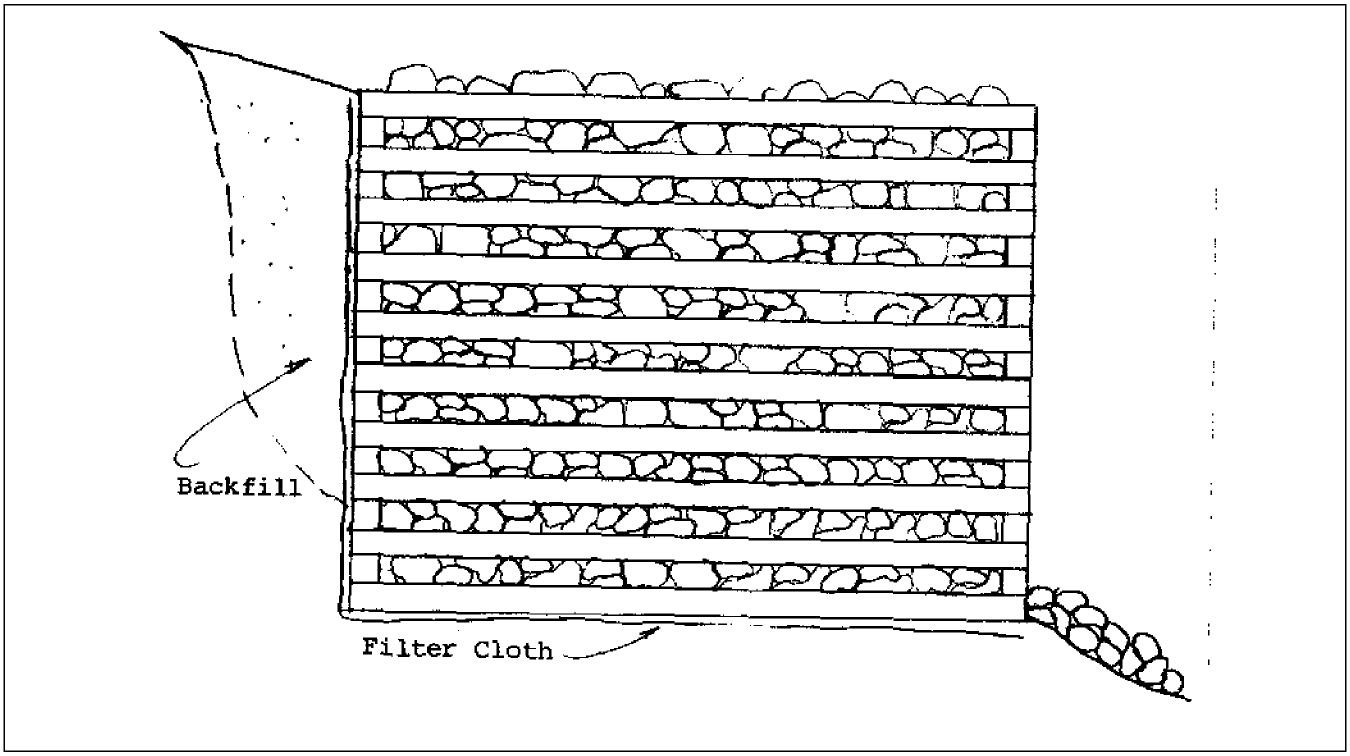

Figure D-20. Timber crib bulkhead cross section

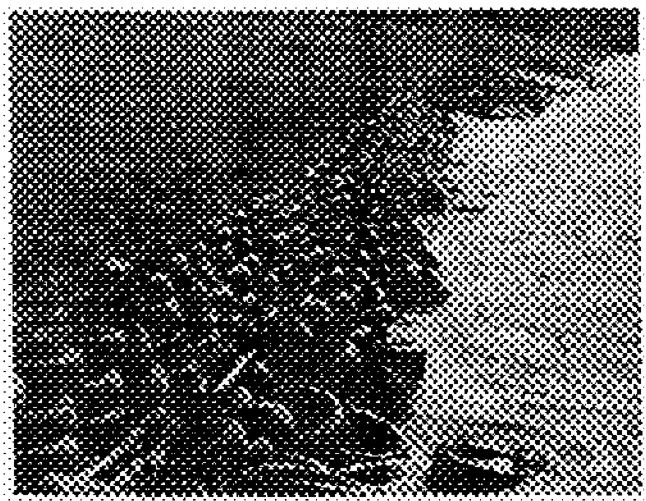

Figure D-21. Stacked rubber tire bulkhead, Port Wing, WI

anchors, similar to those used for power poles. Nonwoven filter cloth was used behind the structure. Interconnections between tires were made with 40-d galvanized spikes with steel push nuts. These proved to be weak, however, and many tires were lost during the first 12 months. Later accretion of the beach in front of the structure may have served to protect it since subsequent damages occurred at a slower rate. A stronger connector would be necessary to achieve long-term stability.

D-17. Used Concrete Pipes

a. General. Used concrete pipes can be placed on end, side by side, to form a continuous wall. To increase stability, the pipes are filled with gravel or other beach materials, and a concrete cap may be employed to ensure retention of the gravel. Filtering must be provided to prevent loss of soil between the cracks in the pipes. The protection is also a crucial consideration.

b. Prototype installation (Figures D-23 and D-24). A typical structure was built around 1976 along the northwest shore of Trinity Bay in McCollum County Park, Beach City, TX (final report on Shoreline Erosion Control Demonstration Program). The 800-ft-long bulkhead consists of a single row of vertical concrete pipes. The units were cracked, chipped, or otherwise unsuitable for culvert use. The pipe lengths were 4 ft, but the diameters varied from 36 to 90 in. Figure D-23 shows the remnants of a

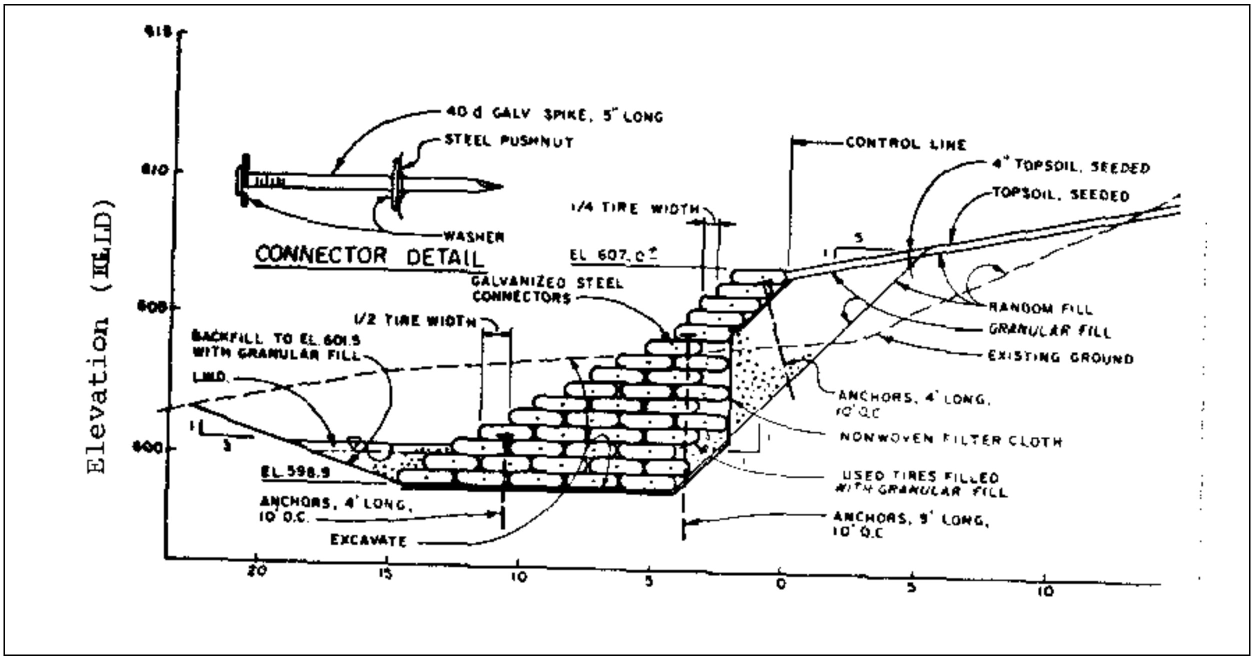

Figure D-22. Stacked rubber tire bulkhead cross section

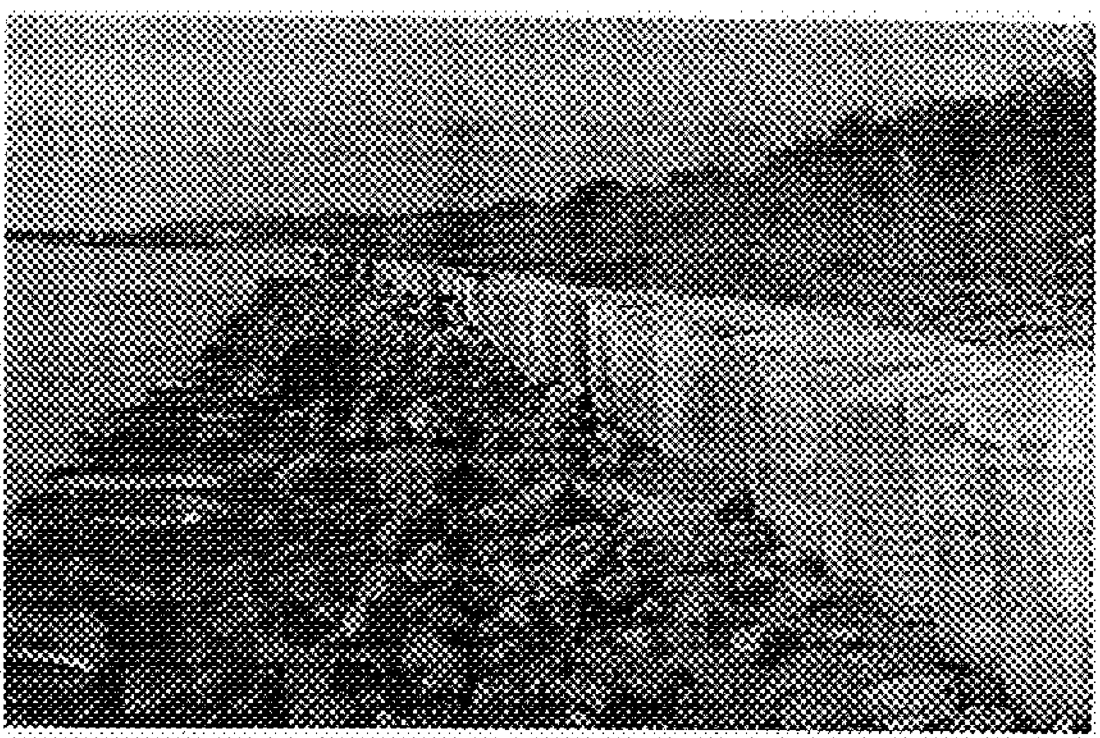

Figure D-23. Used concrete pipe bulkhead, Beach City, TX

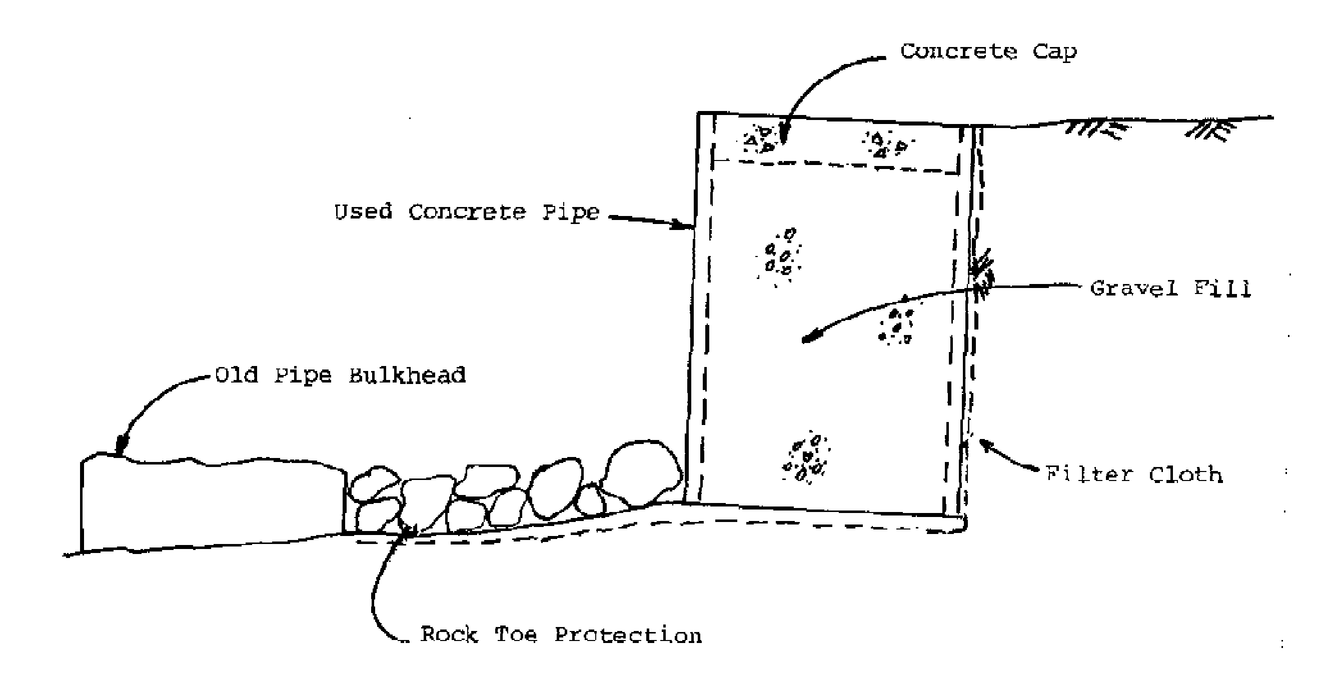

Figure D-24. Used concrete pipe bulkhead cross section

previous device that was built using 18- to 36-in. pipes which was destroyed during Hurricane Carla. As originally built, the structure had no toe protection or filtering system, and the fill within the pipes was not protected. As a result of a July 1979 storm, several pipes were damaged, and some backfill was lost from behind the pipes. Repairs included a concrete cap to protect the pipe fill, cement grouting of the gaps between pipes, and placement of broken concrete toe protection. Subsequent damages to the structure were limited. Fortunately, the relatively low height of the structure precluded damages that would have occurred in taller structures due to the excess hydrostatic pressures that could have developed by blocking the gaps between the pipes with concrete. Use of filter cloth or gravel filter during initial construction would have been a preferred method.

D-18. Longard Tubes

a. General. Longard tubes are patented, woven, polyethylene tubes that are hydraulically filled with sand and available in 40- and 69-in. diameters and lengths up to 328 ft. Placement is usually on a woven filter cloth that extends 10 ft seaward of the tube. A small 10-in. tube, factory-stitched to the seaward edge of the filter cloth, settles under wave action to provide toe protection. The primary advantage of a Longard tube is the ease and speed of construction once equipment and materials are in place. Repairs can be made with sewn-on patches. The major disadvantage is vulnerability to vandalism and damage by waterborne debris. A sand-epoxy coating can be applied to dry tubes after filling to provide significantly greater puncture resistance. This coating cannot be applied in the wet.

b. Design considerations. Tubes can protect a bank toe against wave attack but have little resistance to large earth pressures. Tubes should not be placed directly at a bluff toe because wave overtopping may continue to cause erosion.

c. Prototype installation (Figures D-25 and D-26). Two types of Longard tube bulkheads were built near Ashland, WI, along the shore of Lake Superior, at the base of a 60- to 80-ft bluff (final report on Shoreline Erosion Control Demonstration Program). One was a 69-in. tube topped with a 40-in. tube. A concrete grout wedge was placed between the tubes to help resist overturning. The other structure was a single 69-in. tube. Earth pressures caused the 69-in. tubes to slide or roll lakeward and the 40-in. tube on one device to roll backward and fall behind. Overtopping waves continued to erode the bluff toe, and floating debris caused punctures

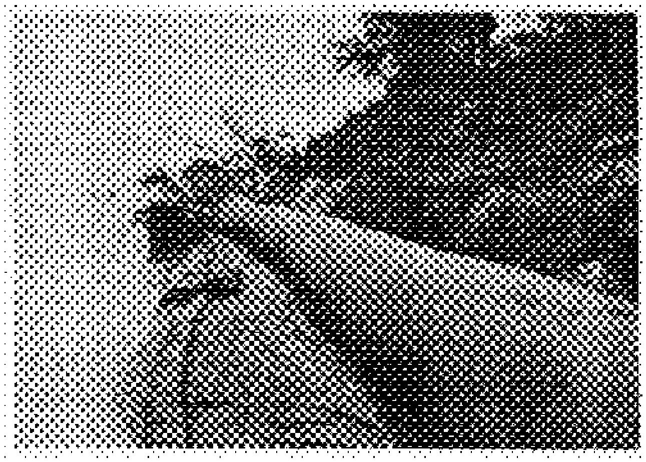

Figure D-25. Longard tube bulkhead, Ashland, WI

in several locations. These continued to enlarge and eventually caused a significant loss of sand fill from within the tubes. This was true despite the sand-epoxy coating. Placement of the tubes away from the bluff toe may have resulted in better performance.

D-19. Stacked Bags

a. General. The uses of bags for revetments was discussed in paragraph B-19. Similar consid erations apply to bulkhead construction, except that the bags are stacked vertically and are used to retain a backfill.

b. Prototype installations. No examples are known. The cross section and discussion of the hogwire fence and sandbag bulkhead (paragraph D-12) would generally apply here except that no fencing would be used. A possible section is shown in Figure D-27.

D-20. Gabions

a. General. The use of gabions for revetments was discussed in paragraph B-20. Gabions can also be stacked vertically to construct bulkheads. These can be stepped up a slope, or the structure face can be placed at a small inclination to increase stability. Toe protection can be provided by extending baskets out along the bottom a distance sufficient to provide a cutoff in the event of scour. The structure must be stable against sliding and rotation considering any eroded depth at the toe.

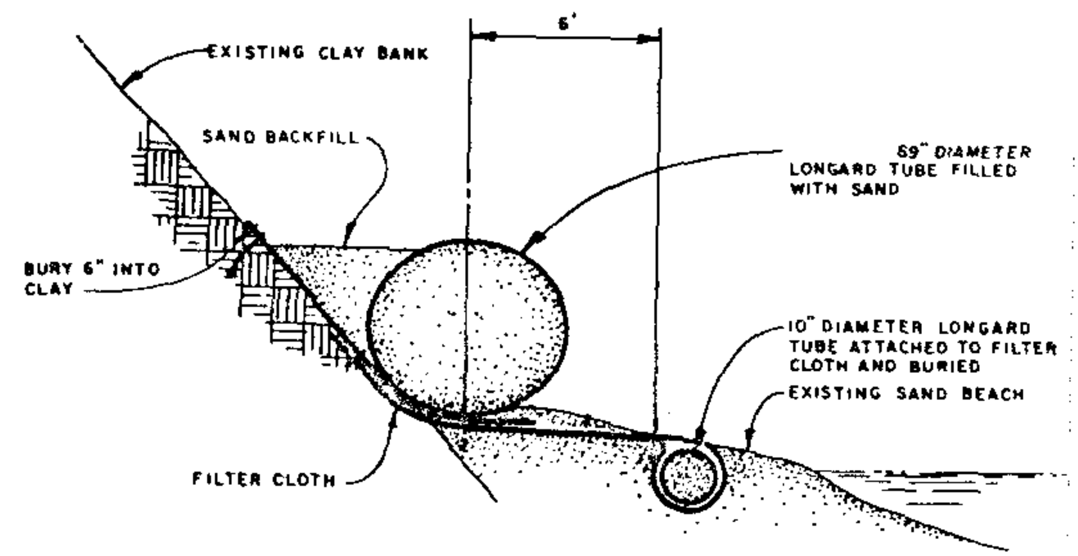

Figure D-26. Longard tube bulkhead cross section

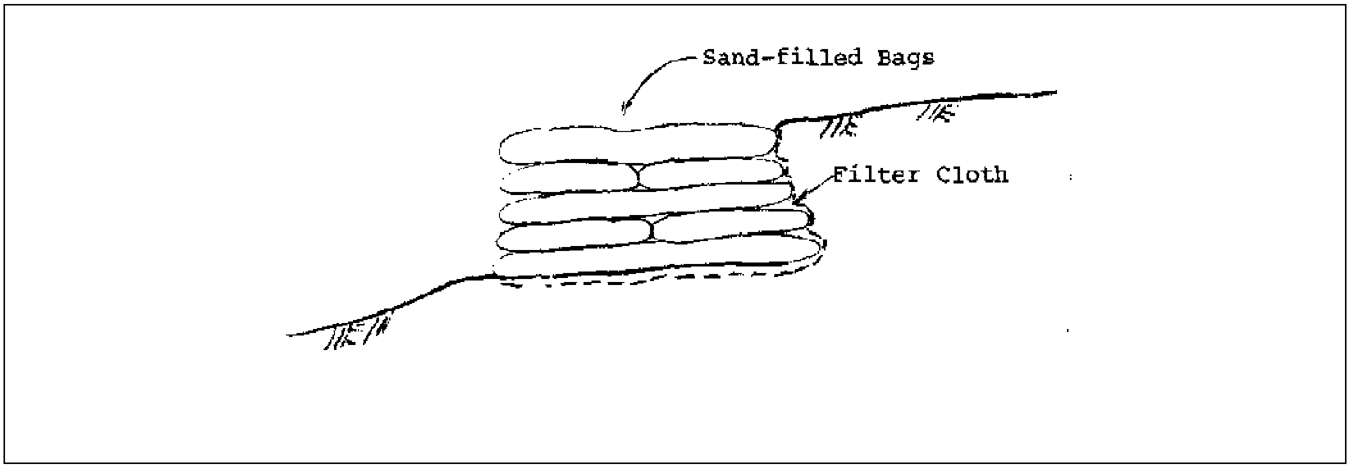

Figure 27. Stacked bag bulkhead cross section

b. Prototype installations. Details on specific sites are unavailable. A photo of an unidentified structure is shown in Figure D-28 along with a possible cross section in Figure D-29.

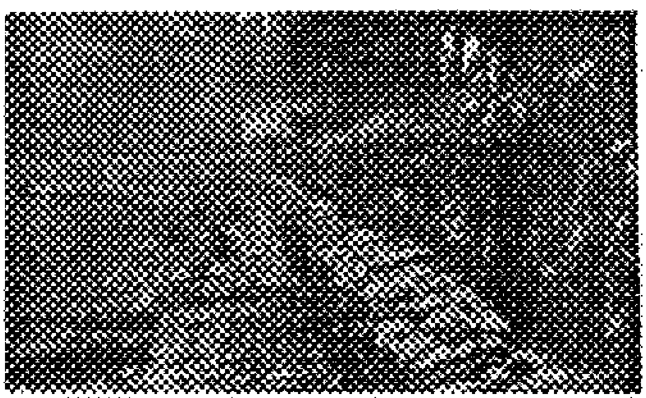

Figure D-28. Gabion bulkhead, possibly at Sand Point, MI

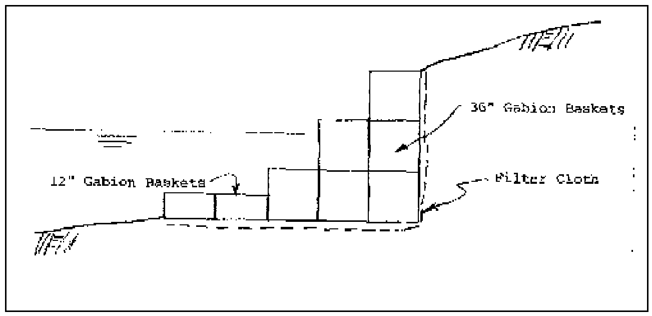

Figure D-29. Gabion bulkhead cross section